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Design and construction of quay wall using geotextile

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ABSTRACT: The design and construction of quay wall using Geotextile as reinforcement in shore is described in this paper. Design method, fabric selection, backfill materials, method of construction are discussed. These include for example, required tensile strength, type of fabric, resistance against sea water, grain size range of backfill materials and compaction. Attention is given to the compaction of backfill materials below sea water level. The following advantages as fast in construction, lowest in cost comparing with sheet pile walls or piling were also considered.

1 INTRODUCTION

1.1 Description of the project

To the author's knowledge, this paper presents the first use of Geotextile for quay construction in Indonesia. The location of the project is at Batam Island of Indonesia, some 30 miles southeast from Singapore.

The main purpose construction of quay wall is to divert the loading and unloading of the interisland vessels which have 1,000 DWT to 2,500 DWT while Batuampar Port was being enlarged for 35,000 DWT vessels.

The project mainly consists of 100 m long reinforced quay wall which has 7.60 m in height above its foundation, with 30x30 sq-cm concrete piles at 5 m center to center spacing along the front of reinforced wall. Anchor rod with 40 tons capacity were installed in order to provide for the horizontal forces created by berthing impact of vessels. Wooden fender were installed at the concrete piles for absorbing the berthing impact, and sand bags barrier were placed along the reinforced wall face inside the Geotextile in order to prevent the erosion of material due to tidal fluctuation and wave actions.

The top elevation of reinforced wall is located at + 3.60 m, the same as the elevation of existing sheet piles quay walls which located at the right side of the reinforced quay wall. Prefabricated concrete slabs with 30 cm in thickness and 3.30 in length were installed for flooring at the top of quay wall, and mooring bolards were provided at 25 m spacing. Figures 1a and 1b show the typical cross section of quay wall and front view of the quay wall, respectively.

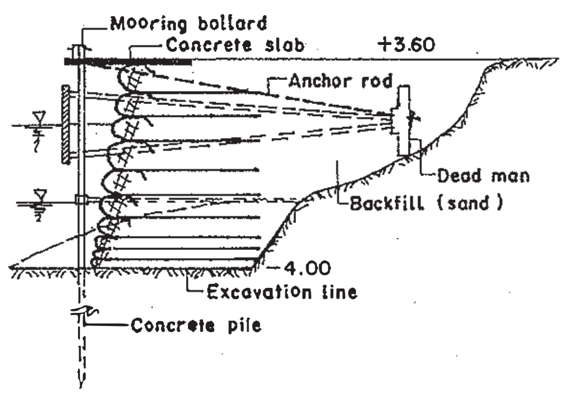


Fig. 1a Typical cross section of quay wall

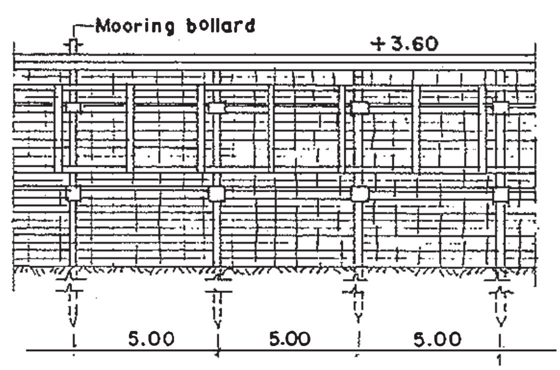


Fig. 1b Front view of quay wall

1.2 Soil investigation

Two boreholes and three Dutch Cone Penetrometer Tests were carried out at the site (Sofoco,1986). Figure 2 shows the location of boreholes and cone tests.

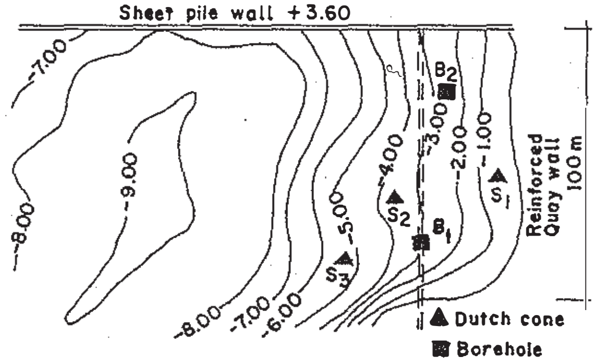


Fig.2 Location of boreholes and cone tests

Several laboratory tests such as specific gravity, grain size analyses, shear box and consolidation tests were undertaken from samples obtained from boreholes. Standard Penetration Tests were also done. Soil profiles shows that a homogenous dense sand layer is encountered from elevation -4.00 m (see figure.3).

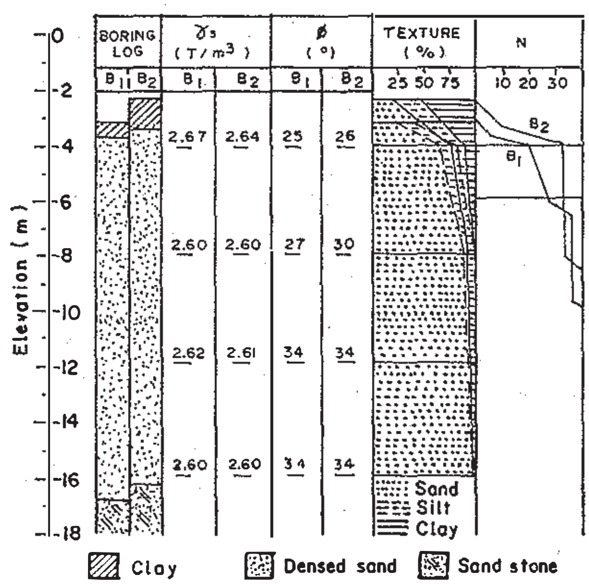


Fig.3 Soil profiles and properties

The N values indicated that the sand layer can be used as foundation of the reinforced wall system. Figure 4 shows the penetration resistantce of the soil (q_c).

Based on the data taken from the field investigation and laboratory tests, the foundation of reinforced quay wall was fixed at elevation -4.00 m, on the sand layer with angle of internal friction (Ø) of 25°.

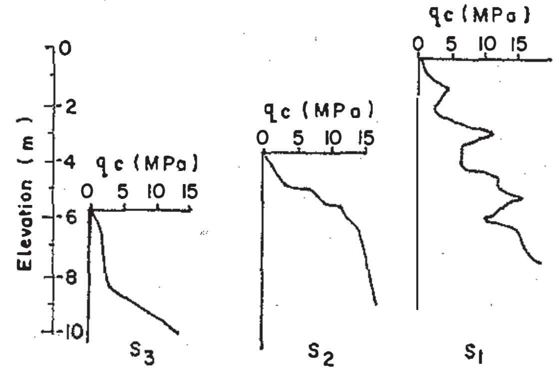


Fig.4 Penetration resistance of foundation

2 DESIGN CONSIDERATION

2.1 Fabric selection

Selection of fabric for reinforcement purposes was mainly influenced by 2 factors, namely: internal and external. Internal factors are considered as tensile strength of fabric, elongation and creep behaviour of fabric under prolonged loading condition, and resistant to the environment, while external factors are considered as height of the wall, working load, time of loading, and backfill material. Koerner and Hausmann (1987) tabulated the relationship between the required tensile strength of fabric and wall's height for reinforcement purposes where higher tensile strength are considered for higher walls.

The tensile strength of fabric is important to control the stability of a reinforced structure. The elongation of fabric should be low, since high elongation will result in large deformation and failure of the structure. In Figure 5 the relationship between stress and strain of fabric according to the material formed fabric are represented (Enka bv, 1985).

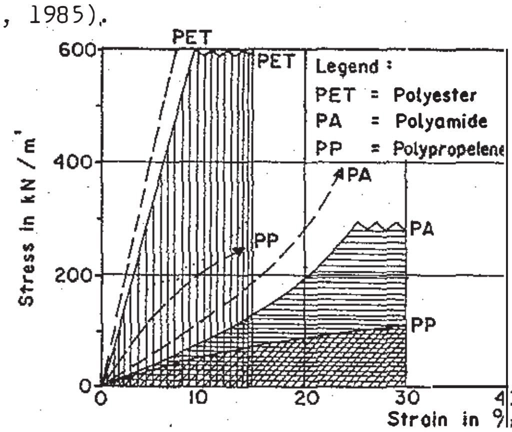


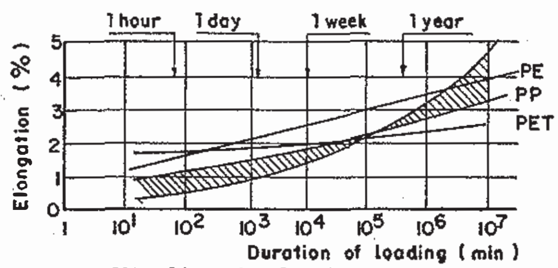
Fig.5 Stress strain relationship of fabric

The fabric tend to elongate when loaded. The elongation corresponds to the load applied to the fabric. The maximum tensile strength at break and simultaneous measured elongation at break are called the ultimate tensile strength and elongation at break, respectively. A 10% elongation at break is considered for reinforcement purposes (Enka bv,1985).

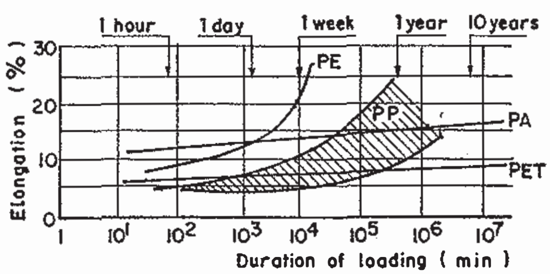
Creep is defined as the increase in length of fabric at constant loading. Creep behaviour of fabric is influenced by construction of fabric, material, working load, and time of loading (Den Hoedt,1986).

In woven fabric yarns should be positioned in straight and exactly to the direction of the load in order to control creep. In non woven fabric, it is not necessary to position the yarns to the direction of loading. In this case, creep is controlled by the bond strength of fabric.

The fabrics were mainly formed from polyamide (PA), polyethelene (PE), polypropelene (PP), and polyester (PET). They produce different properties to the fabrics, making it more and less suitable for reinforcement purposes (Enka bv,1985). Figure 6 shows the relationship between creep ratio (in percentage) and time of loading at 20% and 60% of ultimate load (Den Hoedt,1986).



Creep at 20% ultimate load



Creep at 60% ultimate load

Fig.6 Creep at 20% and 60% of ultimate load

When fabrics are used as reinforcement for prolonged periods of time, the load applied to the fabric should be related to the time to fracture of fabric. The relation between procentage of ultimate strength and time to fracture is represented in Figure 7 (van Zanten,1986).

In general, the acceptance of stress ratio for prolonged time of loading for polypropelene (PP) is 25%, polyethelene (PE) is 25%,

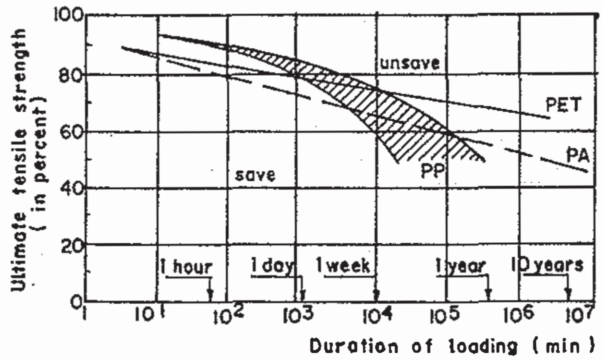


Fig.7 Time to fracture as function of creep load

and polyester (PET) is 40% (Enka bv,1985). The constituent materials of the fabric mainly influenced to the resistance against enviromental attack on fabric, since they have their own typical chemical reaction against acid, alcaline, sea water, and another special conditions. Figure 8 shows the resistance of fabrics against sea water with time. It shows that the residual tensile strength decreased with time (Risseeuw,1984).

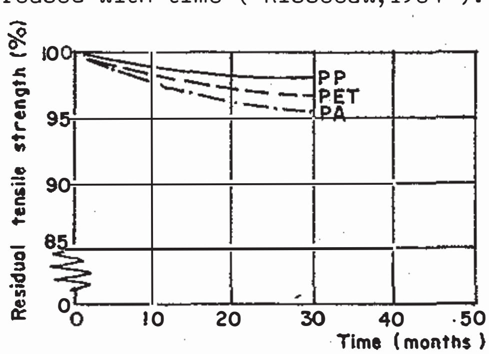


Fig.8 Resistance of fabrics against sea water attack

Based on the above reasons, a woven polyester (PET) with 200 kN/m in ultimate strength is selected for reinforcement in the quay wall.

2.2 Backfill Material

Since half of the reinforcement of the quay wall underwater, there was not recomended to use cohesive soil as backfill material. In addition, it is difficult to control field compaction to desired degree of compaction, since the water contents would exceeds from optimum moisture contents. Sand are recomended for backfill material. Since the fabric opening of woven fabric would permit fine sand to pass through, the grain size of backfill materials should be related to the opening size of the fabric. Figure 9 shows the recomended gradation of sand backfill. Direct shear tests were undertaken in order to measure the angle of internal friction of backfill materials. Based on the tests results, the angle of internal friction was defined at 25° and a sand-fabric friction coefficient at 67% was adopted.

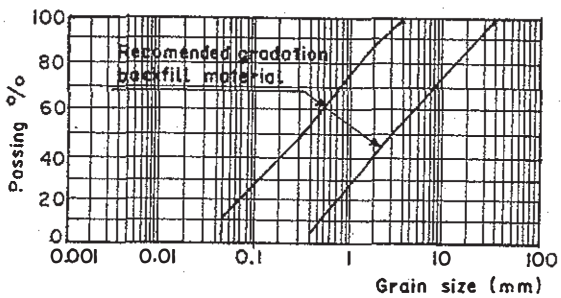


Fig.9 Grain size range of backfill materials

2.3 Design calculations

Due to time related factors in the design of fabric for reinforcement, the following should be considered in the design:

1. Applied load and elongation during construction.
2. Creep ratio during the lifetime of the structure.
3. Required safety factors against failure due to internal, external forces and during various stages of lifetime of structure (Van Zanten,1986).

Broms (1977,1978) developed calculations for reinforcement layer spacing and required anchor length, while the overlapping length was fixed at 2.50 m. Figure 10 shows the external design forces of reinforcement wall system.

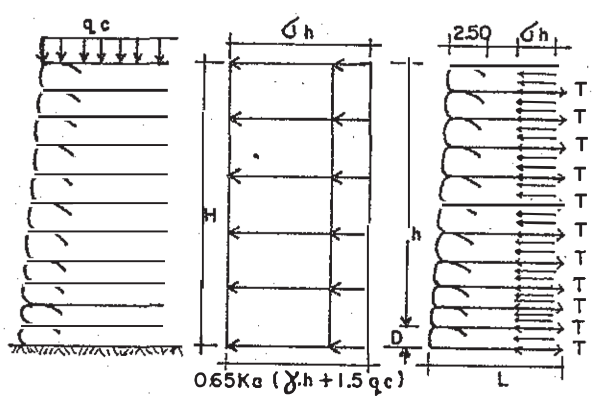


Fig.10 External design forces

Since the backfill materials was sand, the lateral earth pressure is calculated as suggested by Terzaghi and Peck (1967) for design of struts in open cuts in sand as follows:

$$\sigma h = 0.65\ Ka(\gamma \cdot h + 1.5\ q_s) \qquad (1)$$

where σh is the lateral earth pressure, Ka is Rankine's coefficient for active earth pressure, γ is bulk density of backfill, h is the height of wall, and q_s is static overburden pressure, while 0.65 is a safety factor to cover the variation of unit weight and angle of internal friction of backfill material.

Rankine's coefficient for active earth pressure can be calculated as follows:

$$Ka = \frac{1 - \sin \emptyset}{1 + \sin \emptyset} \qquad (2)$$

where $\emptyset$ is the angle of internal friction of backfill material.

The spacings of reinforcement layers was determined by considering the distribution of lateral earth pressure and the effective load take up by fabrics. The layer spacing can be calculated using equation 3:

$$D = \frac{Ta}{\sigma h} \qquad (3)$$

where D is the vertical spacing of reinforcement layers, Ta is the allowable permanent load in fabric, and σh is the lateral earth pressure.

The required anchor length must be sufficient, so that the tension in the fabric can be distributed, and safety factor should be taken into the calculation to cover insufficiency in compaction and variation of unit weight of backfill materials. The required anchor length can be calculated using the following formula:

$$L = \frac{Ta.FS}{\gamma.D.\tan\varphi} \qquad (4)$$

where L is the required anchor length, Ta is allowable permanent load in fabric, FS is safety factor adopted for calculation, γ is bulk density of backfill material, D is the reinforcement layer spacing, and φ is the friction between fabric and backfill materials.

2.4 Stability

In the design for reinforcement wall, the modes of failure should be taken into consideration. The stability of structure should be checked against the safety factor used in the design. The modes of failure of reinforcement system are internal and external stability. Risseeuw and Voskamp (1984) developed the internal stability calculation using limit equilibrium method. External stability consists of 4 modes namely: sliding overturning, bearing capacity failure and rotational.

A limit equilibrium analysis is usually used to check whether the safety factor used in the design is adequate. In this analysis, the lowest possible safety factor was calculated using several configurations of sliding planes from flat to circular surface by varying point B and the angle of β and δ (Enka bv,1985). Figure 11 shows the equilibrium of the reinforcement wedge.

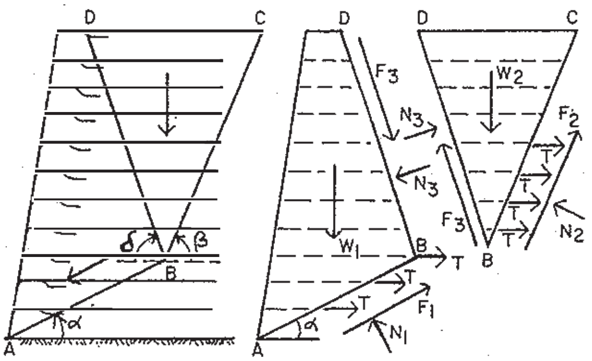


Fig.11 Equilibrium of two reinforced wedges

External stability of reinforced wall is verified using modes of failure as shown in figure 12. These modes were due to sliding, overturning, rotational and bearing capacity failure.

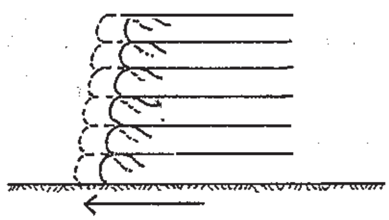


Fig.12a Failure due to sliding

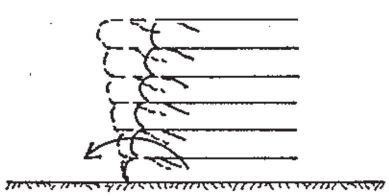


Fig.12b Failure due to overturning

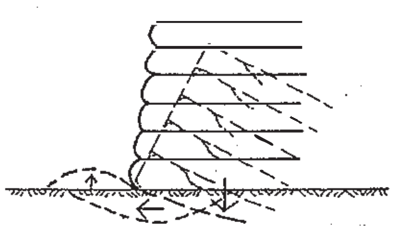


Fig.12c Failure due to bearing capacity failure

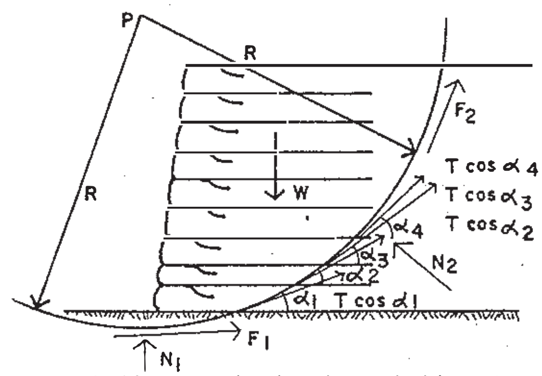


Fig.12d Failure mode due to rotational

Sliding failure occurs due to insufficient friction resistance at the base between fabric and backfill material or the anchor length less than required. The safety factor against sliding can be defined as follows:

$$FS = \frac{\text{resisting forces}}{\text{sliding forces}} \tag{5}$$

Safety factor against overturning can be defined as follows:

$$FS = \frac{\text{resisting moments}}{\text{disturbing moments}} \tag{6}$$

The overall stability is defined as stability against deep rotational sliding. Calculation of the stability is taken based on the method defined by Bishop, modified by introducing of restoring moments contributed by fabrics. The safety factor according to rotational can be defines as follows:

$$FS = \frac{M\ \text{restoring} + \Sigma T\cos\alpha_i R}{M\ \text{disturbing}} \tag{7}$$

Bearing capacity failure occurs due to insufficient strength of the foundation soil. The Terzaghi bearing capacity of the foundation soil can be calculated using the following formula:

$$\sigma_{ult} = c.N_c + \gamma.D_f.N_q + \tfrac{1}{2}\gamma.B.N_\gamma \tag{8}$$

where σ_{ult} is the ultimate bearing capacity, c is the cohesion, γ is bulk density, D_f is the depth of foundation, while N_c, N_q, and N_γ are bearing capacity factors obtained from Meyerhoff's chart (Terzaghi and Peck,1967). The safety factor against bearing capacity failure can be defined using the following formula:

$$FS = \frac{\sigma_{ult}}{\sigma_{act}} \tag{9}$$

where σ_{ult} is the ultimate bearing capacity of foundation, σ_{act} is the maximum load to the foundation. The safety factor in this case should be taken greater than 3.

3 CONSTRUCTION

After the excavation reached the final elevation of foundation and completion of piling the reinforced quay wall was constructed. Compaction of backfill materials were carried out in two ways such as: compaction underwater and above water. Dynamic compaction method was adopted for underwater compaction from elevation -4.00 m up to elevation +1.00 meter. A weight of 2 tons with 1 sq meter plan dimensions hammer was dropped from a height of 3 meter at 1 meter spacing. Track crane was used with this method. The maximum thickness of compaction layer was not more than 50 cm. Compaction of backfill above water level started from elevation +1.00 m up to elevation +3.60 m at the top of quay wall. This portion was compacted using 11 tons vibratory compaction machine in 30 cm lift thickness in 8 passes at the speed not more than 10 km/hr. Sand replacement tests (sand cone tests) were utilized for checking the degree of compaction against the Standard Proctor Compaction Test determined by AASHTO T 99-74 method C from laboratory. Samples were taken by pressing a standard steel mold into the compacted fill, and then the degree of compaction of the sand inside steel mold was measured. The degree of compaction of backfill materials should not less than 90% Standard Proctor Compaction Test determined by AASHTO T 99-74 method C.

4 DISCUSSION

The project was completed within 6 months, and so far there were no special problems encountered during construction.

Compaction of backfill in underwater condition although there was no parameters given for checking the degree of compaction, the result was satisfactory enough. There was no deformation occurs when the compaction above water level was undertaken.

Monitoring of the structure were undertaken after completion the project. A simple horizontal movement measurement was carried out by measuring the change of distance the reinforcement quay wall face from the concrete piles, in order to detect the deformation of the structure. In the first year after completion of the job, the deformation of the structure was very small, under the predicted deformation calculated in the design.

5 CONCLUSION

From the presented case, the following may be pointed out:

1. The use of Geotextile in reinforcement purpose, especially in reinforced quay wall widened the area of application in Civil Engineering Construction.
2. Recent development in the design method of reinforcement wall gives a satisfactory result in construction, and open the various application of Geotextile.
3. Dynamic compaction method which adopted in the compaction for underwater compaction of sand backfill gives a satisfactory result although the degree of compaction could not be measured.

ACKNOWLEDGEMENT

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